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This research contribution develops a methodology for projecting the size of the U.S.-flag tanker fleet over the next 25 years. Such projections are needed to assess whether the Ready Reserve Force can be an economical and effective program for maintaining adequate tanker tonnage to support both military operations and essential economic activity. Domestic crude oil and refined product flows are modeled, and a scheme is developed to allocate the flows between tankers, barges, and pipelines. Relationships are specified to convert the volumes of oil allocated to tankers into tanker tonnage requirements and into requirements for numbers of tankers of various sizes.

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A METHODOLOGY FOR PROJECTING U.S.-FLAG COMMERCIAL TANKER CAPACITY

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ABSTRACT

This research contribution develops a methodology for projecting the size of the U.S.-flag tanker fleet over the next 25 years. Such projections are needed to assess whether the Ready Reserve Force can be an economical and effective program for maintaining adequate tanker tonnage to support both military operations and essential economic activity. Domestic crude oil and refined product flows are modeled, and a scheme is developed to allocate the flows between tankers, barges, and pipelines. Relationships are specified to convert the volumes of oil allocated to tankers into tanker tonnage requirements and into requirements for numbers of tankers of various sizes.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The Center for Naval Analyses (CNA) is conducting a study of strategic sealift under the sponsorship of the Strategic Sealift Division (OP-42). A major objective of the study is to estimate the long-term cost and effectiveness of two strategic sealift programs: the Ready Reserve Force (RRF) and Sealift Enhancement Features (SEF). Both programs are aimed directly at expanding shipping capacity available for military purposes. Under the RRF program, the Navy purchases militarily useful ships from commercial owners who have determined that their ships no longer can be operated at a profit. If the Navy did not purchase these vessels and keep them in a state of readiness, they would most likely be scrapped. Sealift enhancement features purchased and installed by the Navy, such as sea sheds and flat racks, improve the military cargo-hauling capability of active commercial ships and ships in the RRF.

This paper focuses on a methodology for projecting the size of the U.S.-flag tanker fleet over the next 25 years. Such projections are needed to assess whether the RRF can be an economical and effective program for maintaining adequate tanker tonnage. The projections themselves are reported and analyzed for the years 1990, 1995, 2000, 2005, and 2010 in a separate paper, soon to be distributed. With detailed projections of the size of the tanker fleet in hand, it is possible to estimate the necessary size of the RRF in future years. It must be large enough to fill the shortfall between available U.S.-flag tankers and the number required to support military operations. Once the RRF is sized, its cost can be estimated, and the feasibility of the program can be assessed.

The projections indicate that the tanker fleet will continue to shrink in the years immediately ahead and into the early 1990s. By then, the fleet is expected to have declined to a relatively stable floor; it is not expected to decline much further. An assessment of whether the RRF is the best policy for maintaining required tanker fleet capacity must be made on the basis of the size, cost, and feasibility of the RRF at the time when the commercial tanker fleet "hits bottom." Otherwise, resources may be wasted by continuing for too long to pursue a policy that may prove to be inadequate for the 1990s.

The RRF was initiated by the Navy as a stopgap; the commercial fleet had declined to the point where adequate strategic sealift capacity was only marginally available. The Navy did what it could to bolster military shipping capacity in the short run. Over the longer run, however, a cost-effective policy

for maintaining adequate tanker capacity may consist of actions other than increasing the tanker component of the RRF. Until other options are examined, it is not clear that the RRF by itself will be the best program for maintaining the capability to deliver fuel to U.S. forces during wartime.

By the 1990s the commercial fleet may have contracted to the extent where all the options for maintaining the tanker capacity under U.S. flag that is required by the DOD *Sealift Tanker Study* may prove to be prohibitively expensive. The remaining option for delivering the fuels required to support military operations is outsourcing, i.e., reliance by DOD on foreign fuel sources and possibly on foreign-flag tankers. The use of such a strategy would be a major departure from current logistical plans and would require a lengthy period for study and implementation.

The RRF has a natural limit, one that is determined by the size of the commercial fleet. The availability of both merchant sailors and shipyard capacity depends upon the total fleet—the sum of tankers, liners, and dry bulkers. If the overall fleet declines by too much, not enough merchant mariners would be available to operate RRF tankers, and enough shipyard capability to activate the reserve tankers within 20 days might not exist. Under such circumstances, a relatively large RRF would not be feasible. Even if maintaining a large number of tankers in the RRF is cheaper than subsidizing them in commercial operations, the RRF is not necessarily the best policy choice. This aspect of the problem cannot be completed without first projecting the dry cargo component of the U.S.-flag fleet.

Long-term tanker projections are needed to identify a floor for the commercial tanker fleet, and both the size and the date of arrival of that floor are important in assessing the right policy combination to fill the military shortfall. If it appears that the RRF indeed would be too costly or unworkable, other alternatives need to be started well ahead of time, because their implementation could take years. This is a key reason for making long-term projections of U.S.-flag commercial fleet size, rather than projections that have only a 3-to-5-year horizon.

PETROLEUM FLOWS AND TANKER DEMAND

A projection of the supply of tankers requires a detailed analysis of the demand for tankers, and tanker demand ultimately is derived from the demand for refined petroleum products. U.S.-flag tankers transport domestic crude oil to refineries and refined petroleum products to final markets. Under the Jones Act, U.S.-flag tankers enjoy exclusive rights to the domestic trade in crude and refined petroleum products. In fact, domestic shipments of petroleum are the key factor determining the size of the U.S.-flag tanker fleet, because U.S.-flag tankers transport only a small share of imported oil. High-cost U.S. ship operators generally have not been competitive in international oil markets, and in recent years their competitive disadvantage has worsened because the government has curtailed previously existing subsidies. Construction differential subsidies (CDS) have been eliminated, and no new operational differential subsidies (ODS) are being granted, although payments under existing contracts are continuing.

At present, 18 U.S.-flag tankers are operating in foreign commercial trades, and the Military Sealift Command (MSC) operates 22 tankers. These vessels, as well as those in the Jones Act trades, are potentially available to support military operations, but the projection methodology presented below pertains only to the Jones Act trades. The foreign trade and MSC components of the U.S.-flag fleet can be projected without a formal modeling effort. In the absence of CDS payments, no new U.S.-flag tankers will enter the foreign trades, and some tankers currently operating in them are opting to pay back their CDS funds and enter the domestic trades. The number of MSC charters is not expected to deviate much from current levels in the years ahead.

The U.S.-flag tanker fleet is supported primarily by the Alaskan oil trade. Crude oil from the Alaskan North Slope is transported from Valdez to refineries on the West Coast, the Gulf Coast, and the East Coast; and also to the Virgin Islands, Puerto Rico, and Hawaii. Another potential source of tanker demand is derived from Offshore California (OC) production; it is expected to rise rapidly during the next 5 years, and sizable amounts are expected to be shipped to Gulf and East Coast refineries. Although at present more crude oil is produced in the Gulf states than in any of the other four Petroleum Administration for Defense Districts (PADDs), Gulf Coast (PADD III) producers ship relatively little crude out of the region, and what is sent out travels by pipeline. The bulk of PADD III crude is refined locally.

In contrast, more refined petroleum products are shipped out of PADD III than out of the other four districts combined. Most is sent to the East Coast (PADD I), with sizable amounts also moving to the Midwest (PADD II). The vast majority of these shipments are by pipeline, and more than half of the refined products that move to the East Coast over water is carried on barges. Due to their lower operating costs, barges might capture a growing share of the waterborne Gulf-to-East Coast trade in the years ahead.

THE TANKER DEMAND MODEL

As noted, tanker tonnage requirements are determined by shipments of crude and refined products. Shipments, in turn, depend largely upon:

- The volume of domestic crude oil production
- The location of domestic crude oil fields
- The location of domestic refineries
- Domestic demand for refined products
- The location of final markets for refined products.

The relationships among the major oil market variables are depicted in the tables below.

Table 1 shows projected crude oil flows for 1990 for each of the five PADDs, for a sixth region composed of the Virgin Islands and Puerto Rico (VI/PR), and for a total composed of all six regions. (Throughout the paper this total will be referred to as "total U.S.") Table 2 displays similar flows for refined products. The VI/PR region is included because waterborne trade into and out of Puerto Rico is controlled by the Jones Act, and although the Virgin Islands are not under the Jones Act, U.S. crude may be shipped there for refining. This is significant because, in general, U.S. crude oil exports are not permitted.

The purpose of this paper is to present a methodology, not to report final quantitative estimates. Accordingly, the numbers in the tables will not be emphasized here; a second paper will provide such explanation and analysis for 1990, 1995, 2000, 2005, and 2010.

TABLE 1

PROJECTED CRUDE OIL FLOWS IN 1990
(Thousands of barrels per day)

	PADD I	PADD II	PADD III	PADD IV	PADD V	VI/PR	Total
Sources							
Crude oil production	80	804	3,618	563	2,975	0	8,040
Crude oil imports	925	1,313	2,310	27	220	265	5,060
Receipts from other PADDS	115	849	695	0	0	167	
Total crude supply[a]	1,120	2,966	6,623	590	3,195	432	13,100
Uses							
Crude runs	1,080	2,966	5,912	452	2,258	432	13,100
Shipments to other PADDS	40	0	711	138	937	0	
Crude oil exports	0	0	0	0	0	0	0
	1,120	2,966	6,623	590	3,195	432	13,100

a. For the total U.S., total crude supply is the sum of crude oil production plus crude oil imports – 13,100 in 1990. For each PADD, total crude supply also includes receipts, but for the total U.S., receipts are offset by an equal volume of shipments. Both receipts and shipments total 1,826 for 1990. Hence, total crude supply for the total U.S. is less than the sum of the total crude supplies of the PADDs.

The algorithm generating the output shown in tables 1 and 2 depends upon a full accounting of oil flows, in the sense that sources or supply must equal uses or demand both in the U.S. as a whole and in each PADD. Table 1 shows that for the total U.S., crude oil production plus crude oil imports must equal crude refinery runs plus exports. There are no other options. For a given PADD, the relationship is slightly more complex because it can ship crude to other PADDs and receive crude from them. Nonetheless, sources and uses must balance.

Similar relationships are present in the balance between sources and uses of refined products, but there are some differences as well. An additional source of refined products is denoted as other product supply and consists mainly of liquified petroleum gas produced and used in each PADD, refinery gain, and inventory change. Another difference is that consumption is the main use of refined products, while refining is the main use of crude oil. Also, the crude oil and refined product projections are interdependent: crude

refinery runs (table 1) produce an equal volume of refined product (table 2) for each PADD and for the total U.S.

TABLE 2

PROJECTED REFINED PRODUCT FLOWS IN 1990
(Thousands of barrels per day)

	PADD I	PADD II	PADD III	PADD IV	PADD V	VI/PR	Total
Sources							
Refined product production	1,080	2,966	5,912	452	2,258	432	13,100
Refined product imports	1,256	267	327	24	144	133	2,150
Receipts from other PADDS	3,158	1,194	217	84	128	0	
Other product supply	233	384	1,205	63	214	0	2,100
Total product supply[a]	5,727	4,811	7,661	623	2,744	565	17,350
Uses							
Refined product consumption	5,307	4,370	3,783	552	2,494	234	16,740
Shipments to other PADDS	390	401	3,588	71	0	331	
Product exports	30	40	290	0	250	0	610
	5,727	4,811	7,661	623	2,744	565	17,350

a. For the total U.S., total refined product supply is the sum of lines 1, 2, and 4. For each PADD, total refined product supply also includes line 3, receipts from other PADDs. But for the total U.S. receipts are offset by an equal volume of shipments, equal to 4,781 above.

Inter-PADD shipments cannot be projected independently of the other oil market variables listed in the tables. The process begins with projections for the total U.S. of the following variables:

- Crude oil production
- Crude oil imports
- Crude refinery runs

- Crude oil exports
- Refined product production
- Other refined product supply
- Refined product consumption
- Refined product exports.

These projected totals generally follow estimates that are available from the Department of Energy (DOE), the Energy Information Administration (EIA), and major oil companies, including Exxon and Texaco.

Next, the projected totals are allocated among the PADDs. For crude oil production, the distribution is based on regional production patterns projected by EIA. The allocations for refinery activity, refined product consumption, and refined product exports are based largely on analysis by the National Petroleum Council; regional patterns for these variables are changed only moderately from what they were in the mid-1980s. Exports of domestic crude oil are not permitted and thus are projected to remain at zero. The distribution of imports largely follows recent experience for the 1990 projection, but not further out the forecast horizon. The rationale for an evolving geographic pattern of imports is provided in a separate paper that focuses on the numbers in the projection rather than on methodology.

The lines in tables 1 and 2 that still need to be "filled in" are those for receipts, total supply, and shipments. As discussed above, the projected values for receipts and shipments must be such that sources equal uses for each PADD, but that is only a necessary condition for a reasonable projection, not a sufficient one. Numerous values of shipments and receipts might be found to satisfy an accounting identity; an additional requirement is that the projected values make sense in terms of the marketing patterns that have characterized the industry. For example, PADD V receives no crude oil from other PADDs because it has abundant local resources, including oil from the Alaskan North Slope. Over the next two decades, it is highly unlikely that PADD V would receive any crude from other PADDs. Accordingly, projected receipts for PADD V are zero, and in conjunction with the values for the variables that previously were "filled in," PADD V shipments obtain a unique value. Other unique values for shipments and receipts are obtained similarly. PADD II has much more refining capacity than local crude, prompting it to

receive crude oil from other PADDs while shipping none. PADDS III and IV ship crude only to PADD II; so barring a substantial change in distribution patterns, the sum of crude shipments from PADDs III and IV will equal—or at least approximate—PADD II crude receipts. Using relationships such as these, unique values of crude shipments and also of refined product shipments are determined.

THE SHIPMENTS ALGORITHM

This section presents the mathematics of the algorithm that generates the shipments projections for each PADD. The notation corresponding to the variables displayed in tables 1 and 2 is as follows:

CP	Crude oil production
CM	Crude oil imports
CR	Crude oil receipts from other PADDs
RP	Crude runs (also refined product production)
CS	Total crude supply
CSH	Crude shipments to other PADDs
CE	Crude oil exports
RP	Refined product production
RM	Refined product imports
RR	Refined product receipts from other PADDs
RS	Total product supply
CON	Refined product consumption
RSH	Refined product shipments to other PADDs
RE	Refined product exports.

The aggregates in the right-hand column of tables 1 and 2 are denoted by variables with no subscript. Variables that are disaggregated by PADD *are* denoted with subscripts, where i indicates the PADD number. The subscript i takes the values $1, 2, \ldots, 6$, where $i = 6$ denotes the Virgin Islands and Puerto Rico (VI/PR). Letting the crude petroleum production variables serve as an example, CP denotes total crude oil production, and the variables $CP_i, i = 1, 2, \ldots, 6$, denote crude oil production in districts $1, 2, \ldots, 6$. All the variables contain observations for 1990, 1995, 2000, 2005, and 2010. To simplify the notation, however, the time subscript t is suppressed.

The projected values of the totals shown in the right hand column of tables 1 and 2 are all inputs. In terms of the notation used above, the input totals are: CP, CM, RP, CE, RM, RO, CON, and RE.

The algorithm generates a consistent set of inter-PADD crude oil and refined product flows, using the above totals as inputs. To do this, each total is allocated among the six districts. Stated formally, the variables a_{ji} are the proportions of the totals allocated to each PADD, and

$$\sum_{i=1}^{6} a_{ji} = 1 \; for\, each\, j \; .$$

The allocation equations are:

$$CP_i = a_{1i} * CP$$

$$CM_i = a_{2i} * CM$$

$$CE_i = a_{3i} * CE$$

$$RP_i = a_{4i} * RP$$

$$RM_i = a_{5i} * RM$$

$$RO_i = a_{6i} * RO$$

$$RE_i = a_{7i} * RE$$

$$CON_i = a_{8i} * CON \; .$$

In this way, the columns for each of the six districts are filled in for all of the lines in tables 1 and 2 except for inter-PADD receipts (CR_i and RR_i), inter-PADD shipments (CSH_i and RSH_i), total crude supply (CS_i), and total product supply (RS_i).

Inter-PADD shipments and receipts of crude oil are projected under the assumption that the current pattern of crude oil flows reflects production, cost, and marketing efficiencies that are slow to change. Specifically, PADDs IV and V continue to receive no crude from other PADDs. Both districts produce substantially more crude than they refine. In contrast, PADDs II and VI ship no crude; their refinery actively outstrips local crude oil production. Thus,

$$CR4 = CR5 = 0$$

and

$$CSH2 = CSH6 = 0 \quad ,$$

and using the crude oil accounting identity

$$CPi + CMi + CRi \equiv RPi + CSHi \quad , \tag{1}$$

values are determined for $CR2$, $CR6$, $CSH4$, and $CSH5$. (The identity is written under the assumption that $CEi = 0$, because the U.S. does not permit crude oil exports.)

Next, using the assumption that PADDs III and IV continue to ship crude exclusively to PADD II, crude shipments out of PADD III are derived as

$$CSH3 = CR2 - CSH4 \quad .$$

Historically, shipments and receipts have been simultaneously positive for PADD III. From equation 1 above, the difference between PADD III shipments and receipts, denoted D3, can be written

$$\begin{aligned} D3 &= CSH3 - CR3 \\ &= CP3 + CM3 - RP3 \quad , \end{aligned}$$

and crude receipts for PADD III are obtained as

$$CR3 = CSH3 - \mathrm{D}3 \quad .$$

Only shipments and receipts for PADD I remain to be determined. In general, PADD I is a receiver, not a shipper of crude. Its capacity to refine crude oil is much greater than its capacity to produce it. Hence, it imports large volumes and receives some from PADD V. A small volume of crude oil is shipped from PADD I to PADD III via pipeline; none is shipped by water. Utilization of the pipeline constrains PADD I shipments to roughly 40,000 barrels per day. Assuming that these pipeline shipments continue in 1990, $CSH1$ is determined. Observing that crude receipts and shipments are simultaneously positive for PADD I, its receipts are calculated by the same method used for PADD III:

$$\begin{aligned} D1 &= CSH1 - CR1 \\ &= CP1 + CM1 - RP1 \quad , \end{aligned}$$

and

$$CR1 = CSH1 - D1 \ .$$

Inter-PADD shipments and receipts of crude oil are fully derived at this point in the algorithm.

The procedure for projecting shipments and receipts of refined product is quite similar. The Virgin Islands and Puerto Rico are assumed to maintain refining capacity well in excess of what is needed for local consumption. As a result, VI/PR ships refined products but receives none. On the other hand, refineries in PADD V produce to meet local demand; small amounts of refined products are received, but none is shipped. Thus

$$RSH5 = 0 \ ,$$

and

$$RR6 = 0 \ .$$

Values for RR5 and RSH6 then can be obtained from the refined product flow identity:

$$RPi + RMi + RRi + ROi \equiv CONi + RSHi + REi \ . \qquad (2)$$

Next, it is assumed that PADD II continues to ship refined products to PADDS I, III, and IV, and that PADDs III and IV continue to receive refined products exclusively from PADD II. Under these circumstances, refined receipts of PADDs III and IV are simple proportions of PADD II shipments:

$$RR3 = h3 * RSH2 \ ,$$

$$RR4 = h4 * RSH2 \ ,$$

where $h3$ and $h4$ take values of approximately 0.54 and 0.21 for 1990. To solve these equations, it is necessary to project values for $RSH2$ external to this model.

PADDs II, III, and IV simultaneously ship and receive refined products, and the difference between shipments and receipts is obtained from equation 2 above as

$$Di = RSHi - RRi = RPi + RMi + ROi - CONi - REi$$

for $i = 2, 3, 4$. Values for RR2, RSH3, and RSH4 follow as

$$RR2 = CSH2 - D2$$

$$RSH3 = D3 + RR3$$

$$RSH4 = D4 + RR4 \quad .$$

Shipments and receipts for PADD I are all that remain to be determined. PADD I receipts are described by the following equation:

$$RR1 = (1 - h3 - h4) * RSH2 + m * RSH3 + RSH6 \quad .$$

All the variables on the right-hand side previously were determined except for m, which is set outside the model. PADD III sends roughly 75 percent of its refined shipments to PADD II, so m is set at about 0.75 in 1990. With $RR1$ determined, $RSH1$ follows from equation 2.

PETROLEUM REFINERY CAPACITY CONSTRAINTS

Because refining capacity has been declining in the U.S. in recent years and is expected to continue doing so in the years ahead, refinery constraints are included in the algorithm to assure that the inter-PADD flows are feasible.

$$RP_i \leq CAP_i, i = 1, 2, \ldots 6 \ ,$$

where CAP_i is projected refinery capacity in PADD i. Initially, capacity is projected to shrink 2 percent annually through 1990 and then remain flat. There is no programmed correction in the algorithm if a capacity constraint is violated. The correction would be judgmental; most likely it would consist of a cut in crude oil imports and a corresponding increase in refined product imports.

ALLOCATION TO TANKERS, PIPELINES, AND BARGES

For each PADD, crude oil shipments (CSH_i) and refined product shipments (RSH_i) are allocated by PADD of destination and mode of transportation. As noted, the allocation to PADDs of destination follows a pattern similar to the one currently existing, because changes in the location of final markets, refineries, and oil fields usually are gradual. In contrast, the allocation to tankers, pipelines, and barges reflects two major changes: (1) new pipelines by 1990 and (2) increased barge penetration.

The equation set for this algorithm is displayed below. The notation for the dependent variables carries the following interpretation:

- The first letter indicates whether the flow is crude oil C or refined product R.
- The second letter indicates whether the shipment is by tanker T by pipeline L or by barge B.
- The first number indicates PADD of origin.
- The second number indicates PADD of destination.

The coefficients on the right-hand side of the equations are proportions of total crude oil shipments or of total refined product shipments out of a single PADD. For crude shipments, these coefficients begin with D and for refined product shipments they begin with J. The second letter indicates mode of shipment (T, L, or B), the first number indicates PADD of origin, and the second number indicates PADD of destination. Clearly, the sum of the coefficients for total crude shipments out of a single PADD must equal one; likewise, the sum of the coefficients for total refined product shipments out of a given PADD must equal one.

The equations for this algorithm are:

PADD V Crude

$CL53 = DL53 * CSH5$
$CT53 = DT53 * CSH5$
$CT51 = DT51 * CSH5$
$CT56 = DT56 * CSH5$

PADD IV Crude

$CL42 = DL42 * CSH4$

PADD III Crude

$CL32 = DL32 * CSH3$
$CT32 = DT32 * CSH3$

PADD I Crude

$CL13 = DL13 * CSH1$

VI/PR Product

$RT61 = J61 * RSH6$

PADD IV Product

$RL42 = JL42 * RSH4$
$RL45 = JL45 * RSH4$

PADD III Product

$RT31 = JT31 * RSH3$
$RB31 = JB31 * RSH3$
$RL32 = JL32 * RSH3$
$RB32 = JB32 * RSH3$
$RL35 = JL35 * RSH3$

PADD II Product

$RL21 = JL21 * RSH2$
$RL23 = JL23 * RSH2$
$RL24 = JL24 * RSH2$
$RB23 = JB23 * RSH2$

PADD I Product

$RL12 = JL12 * RSH1$
$RB12 = JB12 * RSH1$

This equation set is not exhaustive; flows from some PADDs to others by some transportation modes are excluded because those flows are not now occurring and are not likely to occur. An example of the output from this algorithm is provided in tables 3 and 4 for 1990. In the tables, tanker and barge shipments are aggregated into a "waterborne" category.

PIPELINE CAPACITY CONSTRAINTS

To assure that the projected shipments by pipeline from one PADD to another are feasible, the above algorithm also includes a set of pipeline capacity constraints. Using $CL53$ as an example, these constraints take the form

$$CL53 \leq LCAP53 \quad ,$$

where $LCAP53$ is the projected capacity of pipelines from the West Coast (PADD V) to the Gulf (PADD III).

Pipeline capacities by PADD are estimated from data provided by the National Petroleum Council for existing lines. The capacities of lines projected but not yet built are based on current company plans in the case of those lines expected during the next few years. The capacities of pipelines projected for the outyears of the forecast must be made judgmentally.

TABLE 3

PROJECTED INTER-PADD CRUDE OIL FLOWS IN 1990
(Thousands of barrels per day)

	Receipts						
Shipments	PADD I	PADD II	PADD III	PADD IV	PADD V	VI/PR	Total
			PIPELINE				
PADD I	0	0	40	0	0	0	40
PADD II	0	0	0	0	0	0	0
PADD III	0	642	0	0	0	0	642
PADD IV	0	138	0	0	0	0	138
PADD V	0	0	330	0	0	0	330
VI/PR	0	0	0	0	0	0	0
Total	0	780	70	0	0	0	1,150
			WATERBORNE				
PADD I	0	0	0	0	0	0	0
PADD II	0	0	0	0	0	0	0
PADD III	0	69	0	0	0	0	69
PADD IV	0	0	0	0	0	0	0
PADD V	115	0	325	0	0	167	607
VI/PR	0	0	0	0	0	0	0
Total	115	69	325	0	0	167	676
			TOTAL				
PADD I	0	0	40	0	0	0	40
PADD II	0	0	0	0	0	0	0
PADD III	0	711	0	0	0	0	711
PADD IV	0	138	0	0	0	0	138
PADD V	115	0	655	0	0	167	937
VI/PR	0	0	0	0	0	0	0
Total	115	849	695	0	0	167	1,826

TABLE 4

PROJECTED INTER-PADD REFINED PRODUCT FLOWS IN 1990
(Thousands of barrels per day)

	Receipts						
Shipments	PADD I	PADD II	PADD III	PADD IV	PADD V	VI/PR	Total
			PIPELINE				
PADD I	0	265	0	0	0	0	265
PADD II	100	0	165	84	0	0	349
PADD III	2,345	697	0	0	93	0	3,135
PADD IV	0	35	0	0	35	0	70
PADD V	0	0	0	0	0	0	0
VI/PR	0	0	0	0	0	0	0
Total	2,445	997	165	84	128	0	3,819
			WATERBORNE				
PADD I	0	125	0	0	0	0	125
PADD II	0	0	52	0	0	0	52
PADD III	381	72	0	0	0	0	453
PADD IV	0	0	0	0	0	0	0
PADD V	0	0	0	0	0	0	0
VI/PR	331	0	0	0	0	0	331
Total	712	197	52	0	0	0	961
			TOTAL				
PADD I	0	390	0	0	0	0	390
PADD II	100	0	217	84	0	0	401
PADD III	2,726	769	0	0	93	0	3,588
PADD IV	0	35	0	0	35	0	71
PADD V	0	0	0	0	0	0	0
VI/PR	331	0	0	0	0	0	331
Total	3,157	1,194	217	84	128	0	4,781

PADD V CRUDE OIL TRADE

The equations in the algorithm that allocates oil flows to tankers, pipelines, and barges, and the sample output in table 3 indicate that virtually all projected inter-PADD crude oil movements by tanker originate in PADD V. In addition, the Alaskan oil trade includes shipments *within* PADD V that are an important source of tanker business. Accordingly, in order to project tanker requirements, a more detailed modeling of PADD V crude oil flows is necessary.

The crude oil that is shipped out of PADD V comes almost entirely from two sources: the Alaskan North Slope and Offshore California. Other PADD V crude is refined locally. The purpose of the algorithm below is:

- To fully account for the crude oil flows from the North Slope and from Offshore California

- To disaggregate these flows by trade routes.

When that is done, the demand for tanker tonnage and for numbers of vessels of various sizes can be projected.

The first equation accounts for all North Slope crude:

$$CP5A = VP + VV + VH + VW \quad , \tag{3}$$

where $CP5A$ denotes North Slope crude production and the right-hand variables are crude oil flows moving by tanker (in thousands of barrels per day):

VP Valdez to Panama

VV Valdez to Virgin Islands (via the Cape)

VH Valdez to Hawaii

VW Valdez to West Coast.

The crude shipments to the West Coast and Hawaii remain within PADD V; the others do not.

The second equation accounts for Offshore California crude, including the growing production from the outer continental shelf:

$$OC = OCL + OC1 \quad , \tag{4}$$

where OC denotes total Offshore California production. The right-hand variables once again are flows on trade routes:

OCL Pipeline from California to Gulf Coast

$OC1$ Tanker from California to East Coast (via Panama Canal).

This allocation expects that the All-American pipeline will be operational before 1990; it will have sufficient capacity to transport all Offshore California production to PADD III. (In fact, in the base-line projection discussed below, Offshore California oil moves exclusively to PADD III, and $OC1$ is zero.)

In the previous section, crude oil shipments out of PADD V were disaggregated by PADD of destination and mode of transportation into shipments by tanker to PADDs I, III, and V, and shipments by pipeline to PADD III:

$$CSH5 = CT51 + CT53 + CT56 + CL53 \quad .$$

An alternative disaggregation of shipments out of PADD V is by point of origin:

$$CSH5 = VP + VV + OC1 + OCL + VWL \quad ,$$

where VWL denotes the flow of North Slope crude from the West Coast to the Gulf Coast by pipeline.

The next equation requires that these two decompositions of crude oil shipments out of PADD V be consistent. In other words,

$$CT51 + CT53 + CT56 + CL53 = VP + VV + OC1 + OCL + VWL \quad . \tag{5}$$

This equation accomplishes more than half of the task of assigning crude oil flows out of PADD V to specific routes.

Clearly, there are numerous combinations of values of the variables in equations 3, 4, and 5 that would solve them. The approach taken here is to choose values that reflect the current structure of the crude oil market, as well as likely changes in that structure. It begins by recognizing that pipelines are built because they transport oil more cheaply than tankers, and thus assign sufficient crude to pipelines from PADD V to PADD III to utilize them at a high rate:

$$OCL + VWL = LCAP53 ,$$

where $LCAP53$ is pipeline capacity.

The relationship allows both Offshore California oil and North Slope oil to move to PADD III via pipeline, but for the base-line projection, Offshore California crude will take up most pipeline capacity and VWL will be relatively small. With OCL as input, and OC estimated earlier along with other regional crude oil production variables, $OC1$ is derived as the residual, and equation 4 is satisfied.

The balance required by equation 5 is obtained by assuming that the crude oil flow from Valdez to the Virgin Islands continues to be a small percentage of total North Slope production:

$$VV = b * CP5A ,$$

where b is approximately 0.07.

The flow of crude from Valdez to Panama is derived as the residual:

$$VP = CT51 + CT53 + CT56 + CL53 - VV - OC1 - OCL - VWL .$$

Equation 3 is satisfied by determining the two remaining unknowns: the crude oil flows from Valdez to the West Coast and from Valdez to Hawaii. The latter is assumed to continue to be a small proportion of North Slope crude:

$$VH = d * CP5A ,$$

where d is approximately 0.03. Finally, VW is solved for as

$$VW = CP5A - VP - VH - VV ,$$

and all the consistency conditions are satisfied.

The next step is to disaggregate the crude oil volume carried from Valdez to Panama into separate flows back to North America and the Caribbean. This is necessary because most North Slope crude is carried from Valdez to Panama in tankers that are too large to transit the canal. Smaller ships pick up the crude in Panama and transport it to destinations in PADDs I and III and to the Virgin Islands/Puerto Rico. These flows are:

$PA1$ Puerto Armuelles to U.S. East Coast
$CG1$ Chiriqui Grande to U.S. East Coast
$CG3$ Chiriqui Grande to U.S. Gulf/Puerto Rico.

The allocation proceeds as follows:

$$VP1 = CT51 - OC1$$

$$VP3 = CT53$$

$$VPPR = CT56 - VV \ .$$

North Slope crude destined for PADD I, denoted $VP1$, is the residual after Offshore California crude destined for PADD I is subtracted from total PADD V shipments to PADD I by tanker. All crude moving by tanker to PADD III ($CT53$) is North Slope crude that is shipped first to Panama, denoted $VP3$. As noted above, Offshore California crude allocated to PADD III is expected to be sent through the pipeline. Lastly, crude shipments from PADD V to VI/PR consist of shipments around the Cape to the Virgin Islands (VV), and the residual is North Slope crude that passes through the canal to Puerto Rico, denoted $VPPR$.

The assignment to the trade routes designated above is:

$$CG1 = e * VP1$$

$$PA1 = (1-e) * VP1$$

$$CG3 = VP3 + VPPR \ ,$$

where $0 \leq e \leq 1$.

The volumes of oil that are projected to move via the trade routes discussed in this section are shown in table 5 for 1990. Other components of table 5 are discussed below.

TABLE 5

PROJECTED U.S.-FLAG DOMESTIC TANKER REQUIREMENTS IN 1990

		Thousands of barrels per day	Factor	Thousands of deadweight tons
		CRUDE OIL		
Alaskan North Slope				
Valdez	– USWC	1,462	2.20	3,216
	– Panama	453	4.63	2,097
	– Hawaii	71	2.67	188
	– VI (via Cape)	154		
		2,140		5,501
Puerto Armuelles	– USG/PR	0	2.43	0
	– USEC	38	3.14	119
		38		119
Chiriqui Grande	– USG/PR	338	1.79	605
	– USEC	77	2.37	182
		415		787
Total Alaskan North Slope		2,593		6,409
Offshore California	– USG	0	5.13	0
	– USEC	0	5.72	0
		0		0
		REFINED PETROLEUM PRODUCTS		
Tanker shipments				
USG – USEC		163	2.00	326
USWC – USWC				500
USEC – USEC				150
Total tanker shipments				976
Barge shipments				
USG – USEC		218	1.25	273
USWC – USWC				212
USEC – USEC				700
Total barge shipments				1,185

DERIVATION OF TANKER AND BARGE TONNAGE

By means of the algorithms presented above, oil flows in thousands of barrels per day are allocated to trade routes. These flows are converted to tanker tonnage requirements by applying tonnage factors to them.

Specifically, a tonnage factor converts a daily petroleum throughput requirement into a deadweight tanker or barge tonnage. For example, if 150 thousand barrels of Offshore California crude are shipped by tanker to the Gulf Coast each day, a tonnage factor of 5.13 means that 769.50 thousand (150 * 5.13) deadweight tons of tanker capacity are required. The larger the tonnage factor, the greater is the required tanker tonnage to move a given volume of oil per day. Tonnage factors are higher for:

- Longer voyages
- Slower vessel speeds
- Lengthier port time
- Lower cargo capacity as a percent of vessel deadweight
- Fewer annual operating days
- A greater number of barrels per ton of crude or refined product.

Clearly, tonnage factors can change over time, as the variables listed above change. The tonnage factors used in these projections are based on data supplied by the National Petroleum Council.

Required tonnage to carry crude oil on the trade routes detailed in the previous section is derived by means of the following algorithm:

Within PADD V

$TVW = VW * F1$
$TVH = VH * F2$

Valdez to Panama

$$TVP = VP * F3$$

Out of Panama

$$TC1 = CG1 * F4$$
$$TC3 = CG3 * F5$$
$$TP1 = PA1 * F6$$

Offshore California to Gulf/East Coast

$$TOCS1 = OC1 * F7$$

Total

$$CTANK = TVW + TVH + TVP + TC1 + TC3 + TP1 + TOCS1 \ .$$

The tonnage factors are denoted $F1$ through $F7$, and the dependent variables are the required tonnage on each route. *CTANK* denotes total required tanker tonnage for moving crude oil. Notice that no tonnage is counted for the route from Valdez to the Virgin Islands; this is because such trade can be carried in lower cost foreign-flag tankers.

Earlier it was shown that the projected inter-PADD flows of refined products moving by water consist of:

$RT61$ Tanker, Virgin Islands to East Coast
$RT31$ Tanker, Gulf to East Coast
$RB31$ Barge, Gulf to East Coast
$RB32$ Barge, Gulf to Midwest
$RB23$ Barge, Midwest to Gulf
$RB12$ Barge, East Coast to Midwest.

The latter three flows generate requirements only for small inland vessels with no military value, and thus are ignored. The first category generates little U.S.-flag tanker tonnage, because trade out of the Virgin Islands does not fall under the Jones Act. After eliminating these categories, the projected inter-PADD tonnage to carry refined products consists only of Gulf to East Coast shipments. The equations are:

$$PT31 = RT31 * F9$$

$$PB31 = RB31 * F10 \ ,$$

where the dependent variables are projected tonnage moving by tanker and barge respectively, and $F9$ and $F10$ are tonnage factors.

Intra-PADD shipments of refined products along the East Coast (USEC) and the West Coast (USWC) are another source of demand for both tankers and barges. Generally, however, data are not available on the volume of intracoastal petroleum product flows. For that reason, the tonnage required in the USWC-USWC and USEC-USEC trades are projected on the basis of estimates compiled by the National Petroleum Council of tanker and barge tonnage operating in these trades in 1983. Demand estimates for these coastal tankers and barges are generated over the forecast horizon by indexing the 1983 tonnage estimates to changes in refined product consumption in PADDs I and V. This is not an entirely satisfactory procedure, but at present the lack of better data precludes a more refined effort.

The projected tonnage is denoted:

$PT55$ Coastal tanker tonnage, West Coast

$PT11$ Coastal tanker tonnage, East Coast

$PB55$ Coastal barge tonnage, West Coast

$PB11$ Coastal barge tonnage, East Coast.

Total tanker tonnage required for crude and refined products is

$$TTANK = CTANK + PT31 + PT55 + PT11 \ ,$$

and total required barge tonnage is

$$TBGE = PB31 + PB55 + PB11 \ .$$

An example of this output is provided in table 5.

DERIVATION OF SHIP NUMBERS AND TYPES

The projected tanker tonnage requirements are converted into a projection of numbers and types of vessels by means of the following procedure:

- Existing tankers are assigned to the trades where they are most profitable, according to the scheme shown below:

Tanker size	Preferred trade	Second best
Over 100,000 DWT	North Slope crude	None
70,000 – 99,999 DWT	Chirique Grande to Gulf, East Coast, and Puerto Rico	North Slope crude
40,000 – 69,999 DWT	Chirique Grande and Puerto Armuelles (transiting the Canal) to Gulf and East Coast. Also, product trade from Gulf to East Coast	North Slope crude
Under 40,000 DWT	Coastal product trades	None
Barge Size		
Over 50,000 barrels	Coastal product trades andGulf to East Coast product trades	None

- If the initial allocation results in a surplus of tankers in some trades, the surplus ships will be assigned to a second-best trade if a shortage exists on such a route, and if it is feasible for the ship to operate in that trade.

- The most modern, cost-efficient ships will have first priority for the available tonnage in their preferred trades.

- Vessels that are surplus after all tonnage requirements are met will be scrapped.

- Active ships will be retired at the end of their expected useful lives.

- New ships will be of optimal size for the trades they are constructed to enter.

The allocation scheme will make use of the current list of U.S.-flag tankers. Thus, the ships assigned against projected tonnage for 1990 will consist almost entirely of actual ships, not hypothetical ones. Further out the projection horizon, the ship list will consist mainly of new builds.

For Navy planning, it is important to be able to determine not only the size of U.S.-flag tanker fleet, but also the military usefulness of the ships in the fleet. Militarily useful ships generally have the following characteristics:

- Under 100,000 DWT

- Coated tanks, preferably with epoxy, but otherwise with zinc.

It is also valuable to know whether a tanker has been operating in the crude trades, because additional cleaning is required before refined products such as fuels can be carried in the tanks.

The lists of projected tankers generated by the model include each of the above points:

- Vessel capacity in DWT

- Type of trade (crude or product)

- Type of tank coating (zinc, epoxy, combination, or none) for currently existing ships.

All new builds are assumed to have epoxy coatings, which is now standard practice.

An example of the output from this procedure is shown below:

Ship name	Fleet	Year built	DWT	Coating	Militarily useful
American Sun	U.S.	1969	80,735	Zinc	Yes
Chesapeake Trader	U.S.	1982	50,116	Epoxy	Yes
Arco Independence	U.S.	1977	262,376	Epoxy	No

SENSITIVITY ANALYSIS

The model is used to make a control, or base-line projection of tanker requirements, as well as a series of alternative projections. The control projection is the one that is deemed most likely to occur. It is made on the basis of "consensus" or "mainstream" projections of the important input variables and of the functional relationships between variables.

Alternative projections also are needed for Navy planning, because they quantify the sensitivity of the tanker projection to factors that: (1) cannot be projected with a high level of confidence over a long forecast horizon, and (2) have the potential to effect the outlook for U.S.-flag tanker tonnage importantly.

The prime candidates for sensitivity analysis include:

- Domestic crude oil production
- New pipelines
- Alaskan crude oil exports
- Refined product imports.

The regional pattern of crude oil production changes substantially over the forecast period. Although the consensus view on these changes is included in the base-line projection, it is important to recognize that accurate forecasts of crude oil production are notoriously difficult to make. Unfortunately, they have a large impact on projections. Most domestic crude is produced in PADD III (the Gulf Coast) and PADD V (the West Coast and Alaska). In 1983, PADD III produced about 4.2 million barrels per day, and PADD V produced about 2.8, out of a U.S. total of 8.7. Current projections suggest that by 1990 PADD III production will be down to 3.6, whereas PADD V output will rise to about 3.3 on the strength of new fields in Alaska and off the coast of California. If the West Coast fields fail to pan out, tanker demand would be considerably lower, and if Gulf Coast production declined more rapidly, the impact on tanker demand would be much more moderate because most PADD III oil is refined locally and then shipped via pipeline or barge.

New pipelines present a problem similar to crude oil production. Projecting when and if they will be constructed is relatively difficult, especially in the later years of the forecast horizon, yet they have a large impact on the tanker outlook. One likely addition to the pipeline system – the All-American Pipeline – would carry large volumes of crude from California to the Gulf. The base-line projection includes the All-American Pipeline in 1988, and as a result, the demand for crude carrying tankers is seriously curtailed. Another addition included in the base-line forecast is the proposed trans-Gulf product pipeline from Baton Rouge to Port Everglades. It should be operational by 1987 and reduce requirements for clean product tankers and barges.

If Alaskan crude could be exported to Japan – an enthusiastic potential customer – under present law the oil could be shipped on foreign-flag vessels and so could the crude imported to replace it. This eventuality is treated as an alternative.

Many domestic refineries have closed in recent years because they do not have the downstream processing equipment necessary to refine high-sulfur crude. Others simply cannot compete with low-cost foreign refineries. Some analysts think the U.S. will begin importing more refined products from new refineries in the Middle East and elsewhere, rather than expanding the capacity of domestic refineries. This trade would not be covered by the Jones Act, so in all likelihood it would go to foreign-flag ships. Domestic refining constraints are incorporated into the tanker demand model; any final product demand in excess of refinery capacity is filled through imports. The base-line projection assumes refinery capacity will decline through 1990 and then remain flat. An alternative projection examines a more precipitous decline in domestic capacity.